BROCKWAY SUMMIT FILL SLOPES REPORT

May 2008

INTRODUCTION

This report describes the monitoring activity and results for the Brockway Summit Fill Slopes site. The Fill Slopes plots are located just below Highway 267, one quarter of a mile south of Brockway Summit on the west side of the highway, approximately halfway between Kings Beach and the Northstar-at-Tahoe Resort (Figure 1). The plots are adjacent to and just south of the Tahoe Rim Trail parking area on the shoulder of Highway 267 (Figure 2). The 2004 Highway 267 project that these Basins are a part of includes a series of 7 detention basins along the downslope side of the highway, with road access to each one. The basins were built by cutting into old embankment fills. The test plots are located above two different sediment detention basins. Caltrans refers to these as Basin #1 and Basin #3, respectively. Basin #1 has two restoration treatments and Basin #3 has four different treatments that were chosen for monitoring. Basin #1 was monitored only in 2007, while Basin #3 was monitored in 2006 and 2007. A native site just east of the plots, on the opposite side of Highway 267, was chosen as a reference.

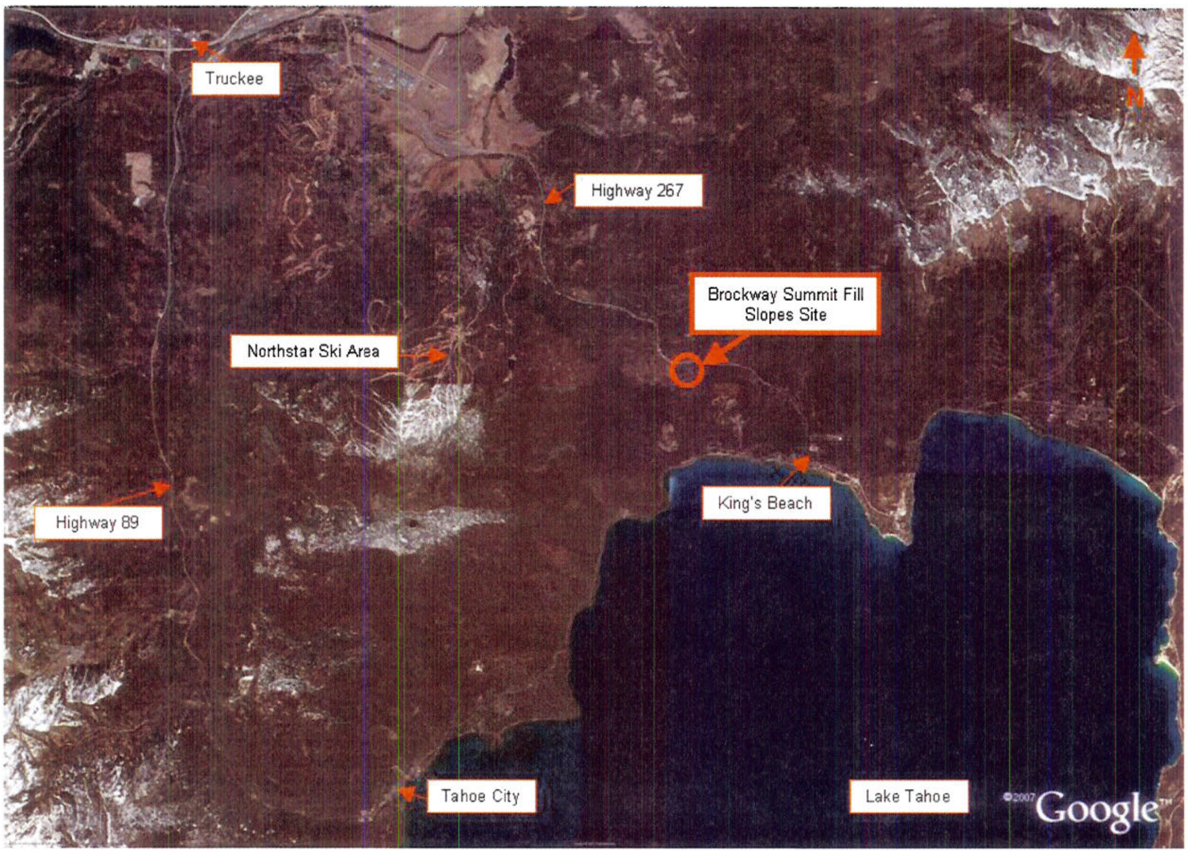

Figure 1. Satellite image showing the location of the Brockway Summit Fill Slopes in relation to the north shore of Lake Tahoe and Truckee.

Two different methods were applied at each basin; one that included tilling to 18 inches (46 cm) and one without incorporation. After installation in 2004, one failure occurred in a section at Basin #3 that was not incorporated. This plot was treated again with a surface application of compost and a biosod mat. A small area at Basin #3 had a treatment that consisted solely of hydroseed application. The erosion control performance of these four different treatments is compared and the results will assist Caltrans in improving their erosion control and re-vegetation techniques.

Figure 2. Satellite image showing the location of the Brockway Summit Fill Slopes plots.

PURPOSE

The Brockway Summit Fill Slope plots were monitored to determine whether a difference exists in the erosion control capacities between treatments tilled to 12 to 18 inches (30 to 46 cm) and treatments without tilling. These treatments received the same soil amendments and only differed in tilling. Data from seed only and biosod treatments will also be reviewed to determine the erosion control capacity of these different treatment techniques. The following measurements will be used to determine which treatments have the greatest capacity for erosion control: infiltration capacity, sediment yield, soil density, nutrient levels, soil shear strength, foliar cover by plants, and ground cover by mulch. Treatment recommendations will be made based on the monitoring results.

SITE DESCRIPTION

The Brockway Summit Fill Slope plots are situated on a south-facing, 25 degree fill slope, just below Highway 267 (Figure 2). The soil originated from volcanic parent material and is classified as a sandy loam, with approximately 13% clay, 17% silt, and 70% sand. The plots have very little canopy cover, and are at an elevation of about 6,992 feet (2,131 m) above mean sea level. The solar exposure ranges between 87% to 96% for all plots with the exception of the seed only plot, which has approximately 36% solar exposure. Surrounding vegetation consists of a mixed conifer shrub community. The dominant tree species are white fir (*Abies concolor*), Jeffrey pine (*Pinus jeffreyi*), and incense cedar (*Calocedrus decurrens*). There are also some sugar pine (*Pinus lambertiana*). Shrubs consist of green leaf manzanita (*Arctostaphylos patula*), tobacco brush (*Ceanothus velutinus*), huckleberry oak (Quercus vaccinifolia), and bitter cherry (*Prunus emarginata*). A native reference site was chosen on the opposite side of Highway 267, several hundred feet above the road. Figure 3 shows the vegetation at the native reference site.

Figure 3. Brockway Summit native reference site. Squaw carpet (*Ceanothus prostratus*), greenleaf manzanita (*Arctostaphylos patula*), and huckleberry leaf oak (*Quercus vaccinifolia*) are the dominant species.

METHODS & MATERIALS

Treatments

Treatment History

In 2004, after slope failures, the Brockway Fill Slopes received varying restoration treatments (Figure 4). Failures continued at the no till treatment in Basin #3 directly after treatment (due to a concentrated flow from the road) and repairs were made in 2005. There have been no failures at any of monitored plots since 2005. Figure 5 shows the Brockway Fill Slopes Basin #1 following the 2004 treatment. Figure 6 and Figure 7 show the plots tilled to 12 to 18 inches and the plots without tilling at Basin #3 in 2006. When utility work was conducted at the basins, wheatgrass was seeded after disturbance.

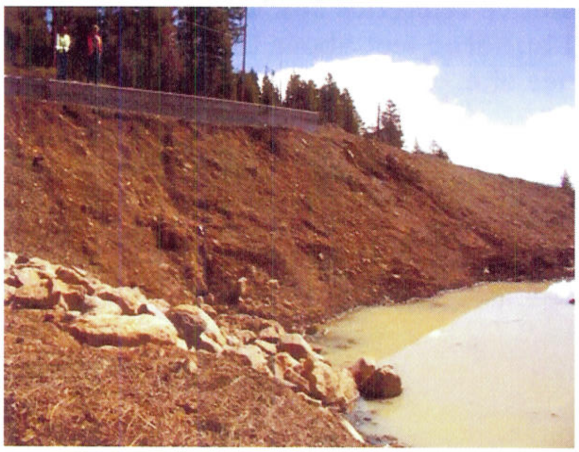

Figure 4. Brockway Summit Fill Slope basin, pre-treatment, 2004.

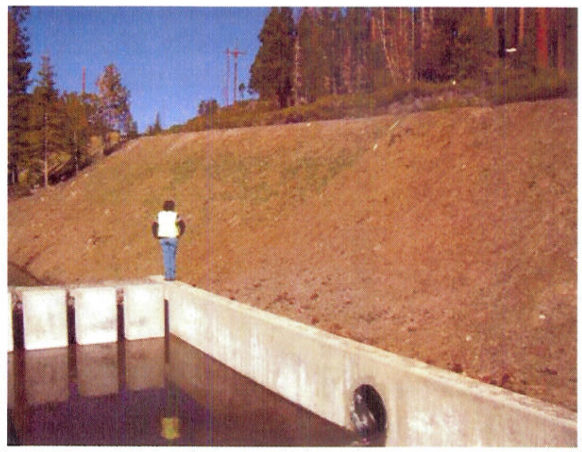

Figure 5. Brockway Summit Fill Slope Basin #1, post-treatment, 2004.

Figure 6. Basin #3, 12 to 18 inch till treatment, 2006.

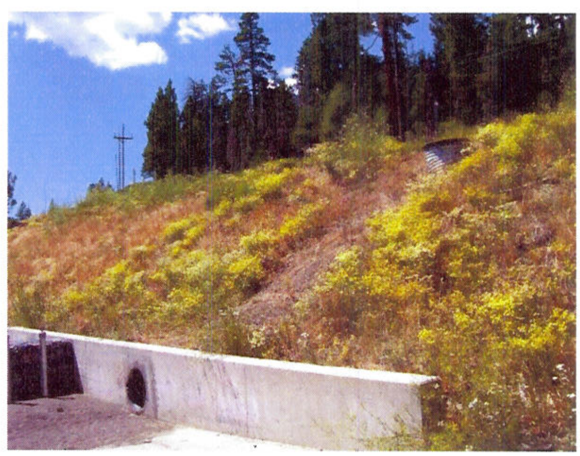

Figure 7. Basin #3 treatment, no till treatment, 2006.

Basin #1

There were two treatments at Basin #1: 12 to 18 inch till and no till. Four inches (7.6 cm) of screened, fine compost were added to both treatments. On a dry weight basis, 100% of the compost passed through a 1 inch (2.5 cm) screen, 95% to 100% passed through a 0.75 inch (1.9 cm) screen, 90% to 95% passed through a 0.25 inch (6.4 mm) screen, 85% to 90% passed through a 0.125 inch (3.2 mm) screen and 0% to 33% passed through a 0.06 inch (1.5 mm) screen. The maximum material length was 6 inches. Both plots were treated with an unknown rate of organic fertilizer (Biosol), native seed (Table 1), tackifier, and 1 inch (2.5 cm) of pine needle mulch. At the 12 to 18 inch till plot, the compost was tilled into the soil to a depth of 12 to 18 inches (30 to 46 cm) with a backhoe. In the following graphs, a (1) will be used to signify plots located at Basin #1.

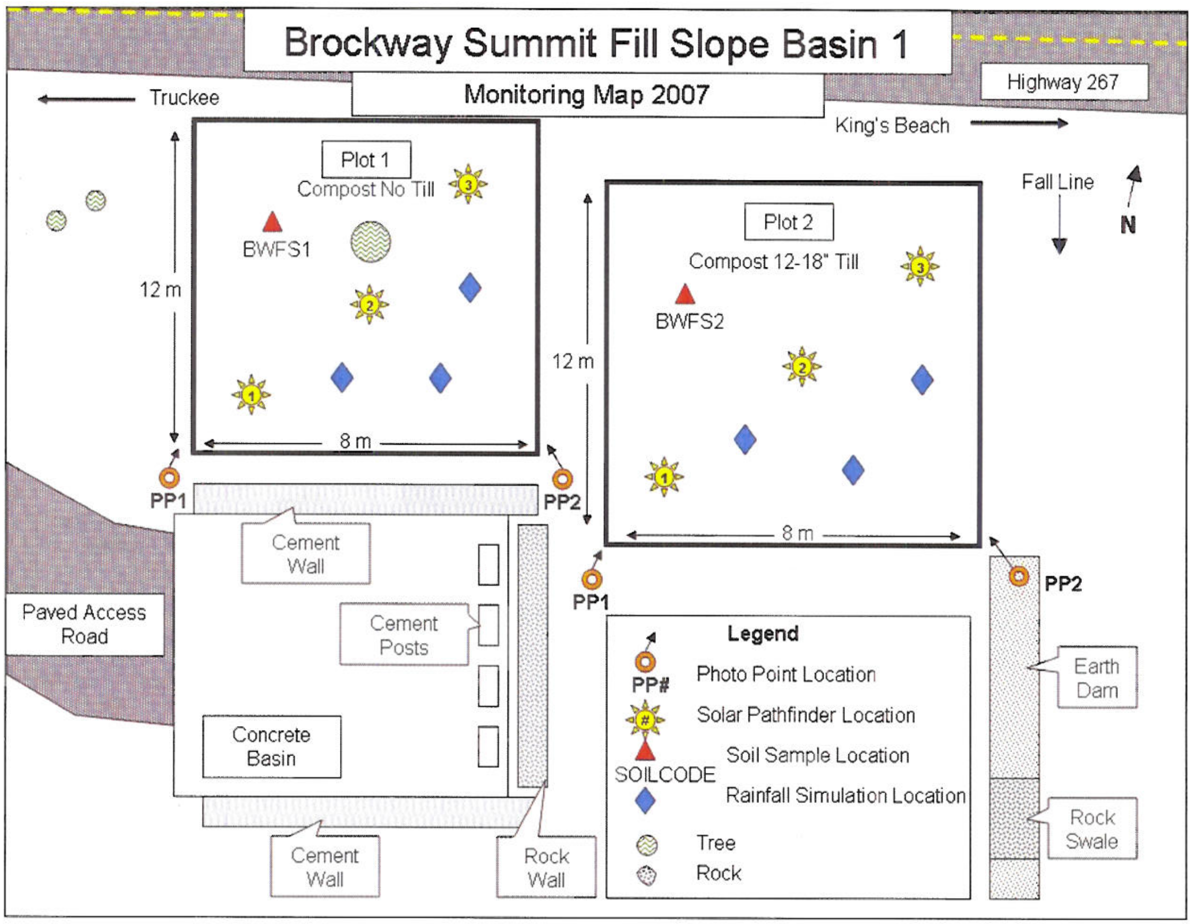

Figure 8. Monitoring and treatment map of Brockway Summit fill slope Basin #1, showing photo point, rainfall, and soil sample locations.

Basin #3

There were four treatments at Basin #3: 12 to 18 inch till, no till, seed only, and biosod. In Basin #3, the no till and 12 to 18 inch till treatments were the same as in Basin #1. The treatment for the seed only plot only included surface seeding (Table 1). No mulch was applied on the seed only treatment (Figure 9). The sod treatment received the same initial treatment as the no till plot, but following the slope failure in 2005, compost and a sod mat of natives grasses and forbs was laid on the surface. Currently, yarrow (*Achillea millefolium*) is the only species present on the mat. In the following graphs, a (3) will signify plots located at Basin #3.

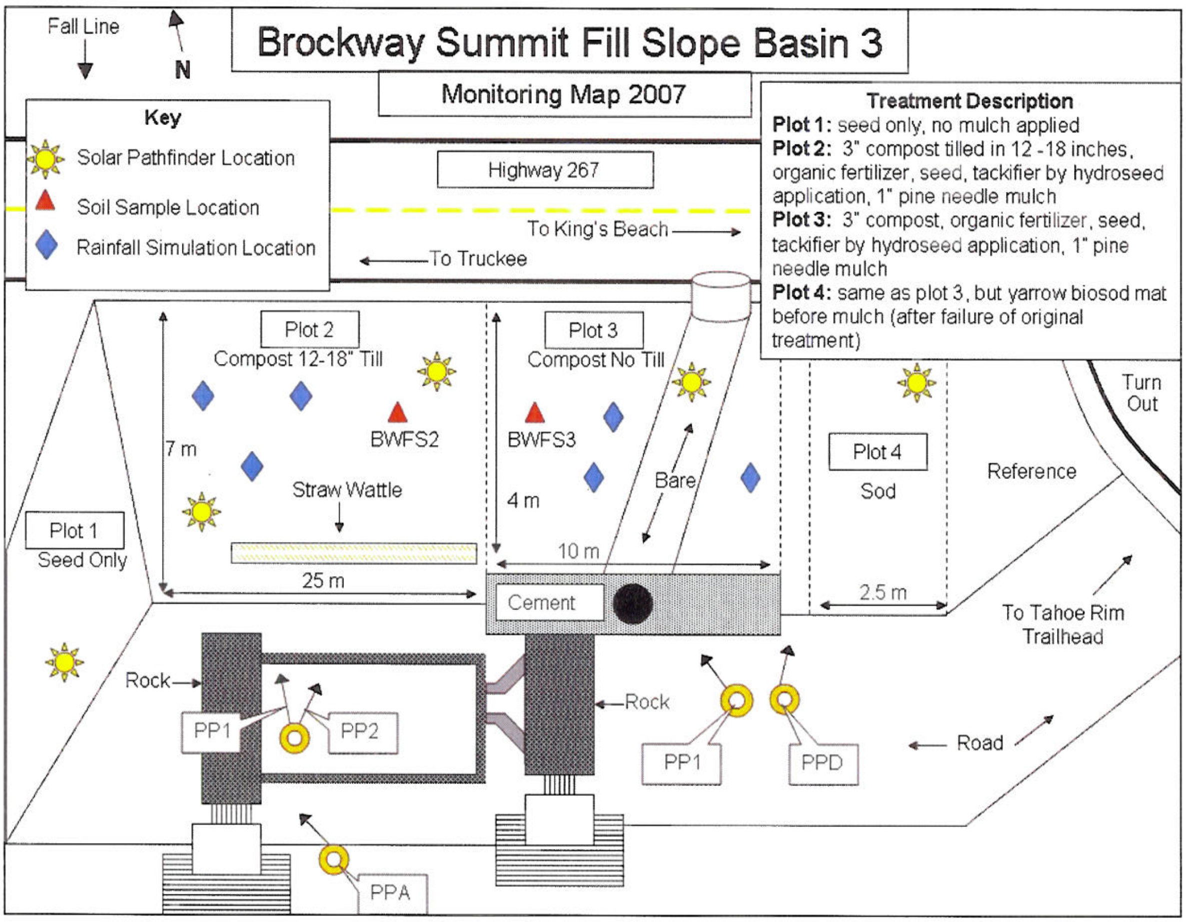

Figure 9. Monitoring and treatment map of Brockway Summit Fill Slope Basin #3, showing photo point, rainfall, and soil sample locations.

Table 1. Seed mix composition for Plots 1 and 2 at Basin #1 and Plots 1, 2, and 3 at Basin #3.

Common Name	Scientific Name
mountain brome	*Bromus carinatus*
squirreltail	*Elymus elymoides*
yarrow	*Achillea millefolium*
Western needlegrass	*Achnatherum occidentale*
sagebrush	*Artemisia tridentata*
rabbitbrush	*Chrysothamnus nauseosus*
elongated hairgrass	*Deschampsia elongata*
nude buckwheat	*Eriogonum nudum*
Spanish lotus	*Lotus purshianus*
Gray's lupine	*Lupinus grayii*
Brewer's lupine	*Lupinus breweri*

Monitoring

Monitoring was conducted at all four plots at Basin #3 in August 2006 and at the 12 to 18 inch till and no till plots at Basin #3 in July 2007 (Figure 9). In 2007, the 12 to 18 inch till plot and the no till plot were monitored at Basin #1. These plots were added in 2007 to provide a comparison to the 12 to 18 inch till and no till plots at Basin #3.

The following monitoring data was collected: foliar and ground cover, soil density, soil nutrient status, infiltration rate, sediment yield, soil shear strength, and general site characteristics. All monitoring was conducted in metric units, while treatment applications were calculated in English units. In the text, both metric and English units are given.

Cover

Cover was measured using the cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 feet (1 m) above the ground. After the rod was leveled, the button on laser pointer was depressed and two cover measurements were recorded (Figure 10 and Figure 11):

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[1] Hogan, Michael. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. 2003. South Lake Tahoe, CA, Lahontan Regional Water Quality Control Board.

1) first cover hit represents the first object intercepted by the laser from a height of 3.3 feet (1 m) above the ground and
2) ground cover hit (second hit) measures vegetation or soil below the first hit cover

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant actually rooted in the ground. The ground cover hit measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris and/or bare ground.

Figure 10. Cover pointer in use along transects.

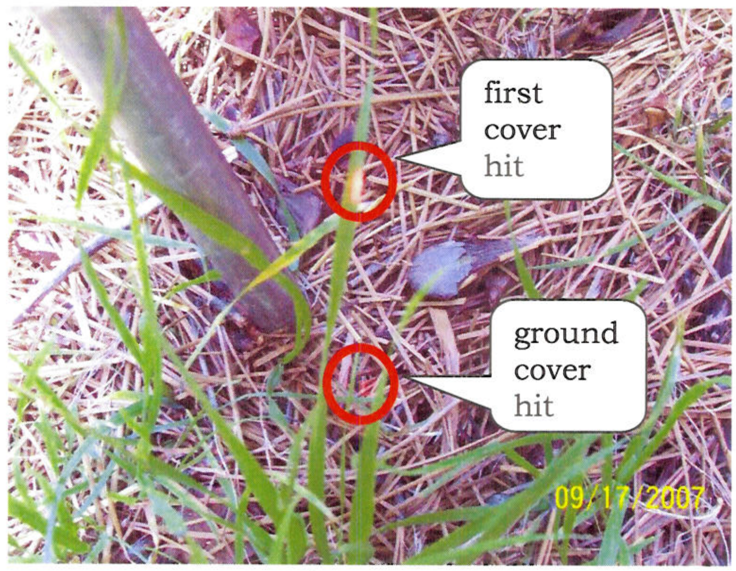

Figure 11. Cover pointer rod with first hit and ground cover hit (second hit) by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Total ground cover comprises all cover other than bare ground. Plant cover, ground and foliar, was recorded by species and then organized into cover groups based on four categories: lifeform (herbaceous/woody), perennial/annual, native/alien (2007 only), and seeded/volunteer (2007 only). Perennial herbaceous species includes perennial seeded grasses and forbs, native grasses and forbs, and non-native grasses and forbs. Annual herbaceous species also include invasive species such as cheatgrass (Bromus tectorum). Woody species are trees and shrubs, both native and introduced. Each species was then classified based on whether it was native to the Tahoe area, or whether it was seeded during treatment. Because data was recorded by species, the amount of cover by species is also available. Species of interest are those that were seeded and problem (invasive) species such as cheatgrass. An ocular estimate of cover at each plot was also recorded and includes many species not detected by cover point sampling. The species list, as well as the ocular estimates of cover, is presented in Appendix A.

Soil and Site Physical Conditions

Soil Density

Soil density was measured along the same transects as the cover point data for all of the plots. A cone penetrometer was used to measure soil density. A cone penetrometer with a one half inch (1.27 cm) diameter tip was pushed vertically into the soil until a maximum pressure of 350 pounds per square inch (psi) (2,411 kPa) was reached (Figure 12 and Figure 13). The depth at which that pressure was reached was recorded as the depth to refusal (DTR). The penetrometer DTR data presented for the rainfall simulation plots was recorded at 250 psi (1,722 kPa) in 2006 and at the current standard of 350 psi (2,413 kPa) in 2007.

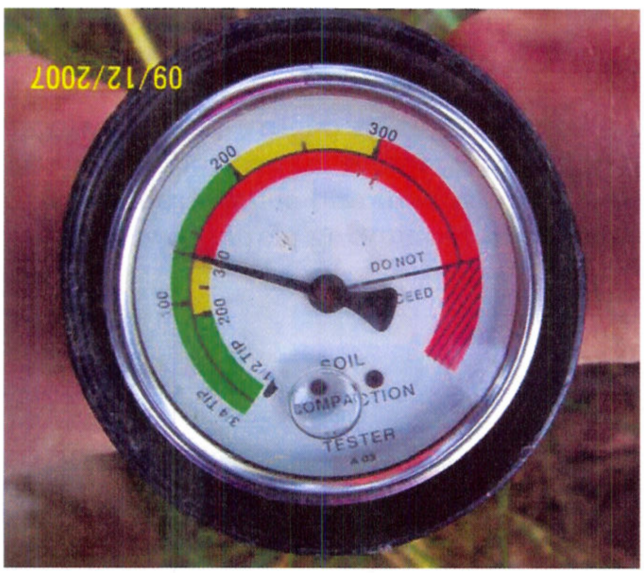

Figure 12. Cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 13. Conducting cone penetrometer readings along transects.

Soil Moisture

A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm) (Figure 14).

Soil Shear Strength

In 2007, soil strength was tested along cover point transects in the same manner as soil density and soil moisture. A hand-held shear vane with 1.5 inch (3.8 cm) long blades was pushed into the soil to a depth of 3 inches (7.6 cm) and turned until the soil could no longer resist the force exerted by the blades and the soil structure either fractured or deformed (Figure 15). This force was then recorded as the "shear stress" in kilopascals (kPa). Forty kilopascals is the maximum force the shear vane can measure. Shear stress values greater than 40 kPa were recorded as 40 kPa. The shear vane was used at both the compost till and the compost no till plots at Basin #3, but only at the compost till plot at Basin #1. The soil at the no till plot at Basin #1 was too dense to allow insertion of the blades into the soil.

This method of determining shear strength has been regularly used in agricultural soils and various laboratory tests, but has not been applied to many forest soils.[2] Coarse fragments or rocks found within the soil may affect shear strength measurements. Regardless, it is important to investigate the usefulness of this tool in assessing the in situ strength of soils with different restoration treatments.

Solar exposure

Solar input was determined using a Solar Pathfinder (Figure 16). Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth and soil microbial activity. It is an important variable to consider when monitoring plant growth, and soil development.

Figure 14. Conducting soil moisture readings along transects.

Figure 15. Soil shear strength tester in use.

Figure 16. Solar pathfinder in use.

Soil Nutrient Analysis

In 2006 and 2007, soil sub-samples were collected from beneath the mulch layer to a depth of 12 inches (30 cm) (Figure 17) at each of the plots that were

[2] Tengbeh, G.T. 1993. The Effect of Grass Root`s on Shear Strength Variations with Moisture Content. *Soil Technology.* Vol. 6. pp. 287-295.

monitored (Figure 8 and Figure 9). Sub-samples collected within a plot location were combined then sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories (Modesto, CA) for S3C analysis, a suite of tests for micronutrients and organic matter, total Kjeldahl nitrogen (TKN), and particle size distribution.

Figure 17. Soil sub-sample collection.

Rainfall Simulation

In 2006, rainfall simulation was conducted at the 12 to 18 inch till, no till, and sod plots at Basin #3. In 2007, rainfall simulation was conducted at the 12 to 18 inch till and no till plots at Basin #1 and Basin #3 (Figure 8 and Figure 9). Rainfall simulation was not conducted at the native plot.

The rainfall simulator "rains" on a square frame from a height of 3.3 feet (1 m, Figure 18 and Figure 19). The rate of rainfall is controlled, and the runoff is collected from a trough at the bottom of the 6.5 square foot (0.6 m^2) frame that is pounded into the ground. The volume of water collected is measured; then the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff was not observed during the first 30 minutes, the simulation was stopped. The average steady state infiltration rate was calculated and will hereafter be referred to as "infiltration rate". The collected runoff samples were then analyzed for the average steady state sediment yield (hereafter referred to as "sediment yield"). Depending on the variability of the plot, one to three rainfall simulations are conducted.

Figure 18. Rainfall simulator and frame.

Figure 19. Rainfall simulator in use with frames at the Brockway Fill Slopes Basin #3.

The cone penetrometer was used to record the DTR surrounding the runoff frames before rainfall simulations (Figure 13). In 2006, DTR pre-rainfall values were taken at a maximum pressure of 250 psi (1,724 kPa) while the 2007 DTR values that were taken at 350 psi (2,413 kPa), the current standard. Soil moisture was also measured in each runoff frame prior to conducting the rainfall simulations. After rainfall simulation, at least 3 holes were dug with a trowel to determine the depth to wetting front, which shows how deeply the water infiltrated within the frame. In 2007, at least 9 holes were dug to measure the depth to wetting.

Different rainfall rates were applied to different plots depending on their propensity to runoff. The initial rainfall rate applied to the test plots was 2.8 inches per hour (72 mm/hr). If runoff was not observed, the rainfall rate was increased to 4.7 inches/hour (120 mm/hr) until runoff was observed or all the water was infiltrated. The rainfall rate of 2.8 inches/hour (72 mm/hr) is more than twice the intensity of the 20 year, 1 hour 'design storm' for the local area.

RESULTS/DISCUSSION

Rainfall

Little to no sediment was produced during rainfall simulation at any of the treated areas in 2006 and 2007 (Figure 20 and Figure 21). The 12 to 18 inch till plot in Basin #3 produced 20 lbs/acre/in (9 kg/ha/cm) of sediment in 2006 and the no till plot in Basin #3 produced 8 lbs/acre/in (4 kg/ha/cm). These are small amounts of sediment in comparison to disturbed or untreated sites.

Similar sites in the Lake Tahoe area that are untreated or disturbed have produced more than 800 lbs/acre/in (353 kg/ha/cm) of sediment.[3]

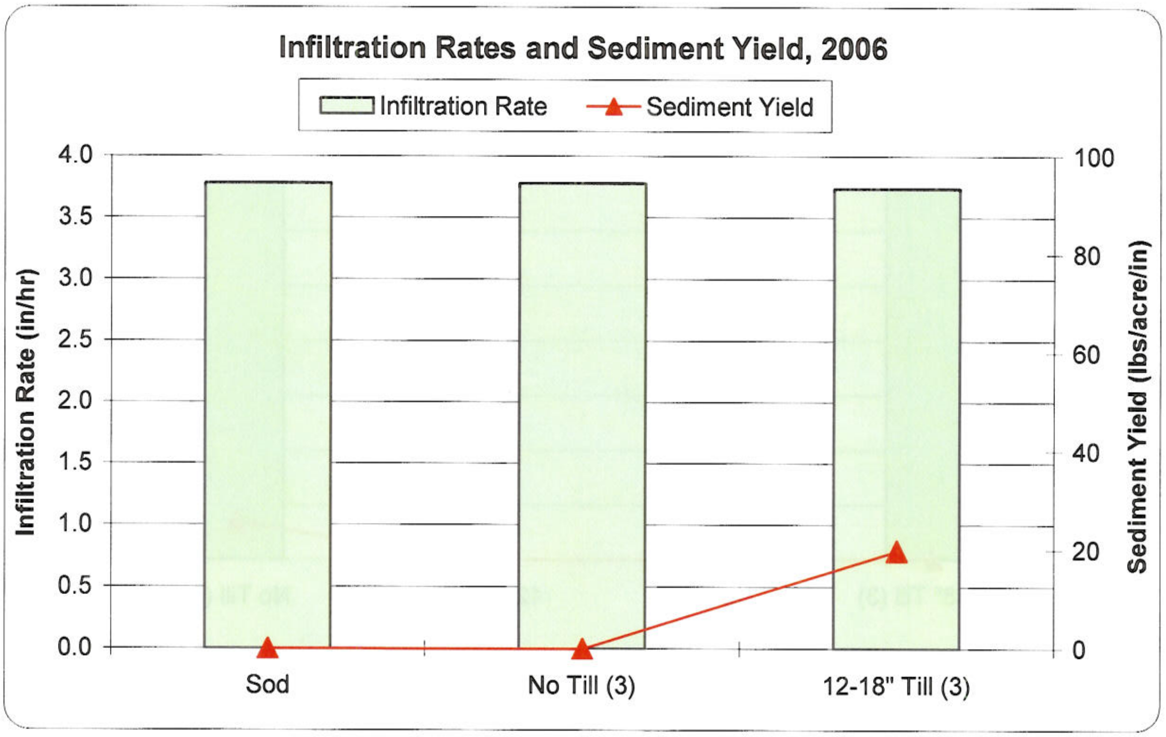

Figure 20. Infiltration Rates and Sediment Yield, 2006. All plots exhibit similar sediment yields and infiltration rates, although the 12 to 18 inch till plot at Basin #3produced a small amount of sediment. Graph is sorted by sediment yield.

Greater than 90% of rainfall was infiltrated at all treated plots (Figure 20 and Figure 21). Infiltration rates range from 3.7 to 4.1 inches/hour (94 to 104 mm/hour). The infiltration rates presented for plots that did not produce runoff are not necessarily the maximum infiltration rates for these plots. The soil may be able to infiltrate water at a higher rate. The plots that produced runoff reached their maximum infiltration rate and could not absorb rainfall at a higher rate.

[3] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin site reports for Resort at Squaw Creek and Northstar Unit 7, unpublished 2008.

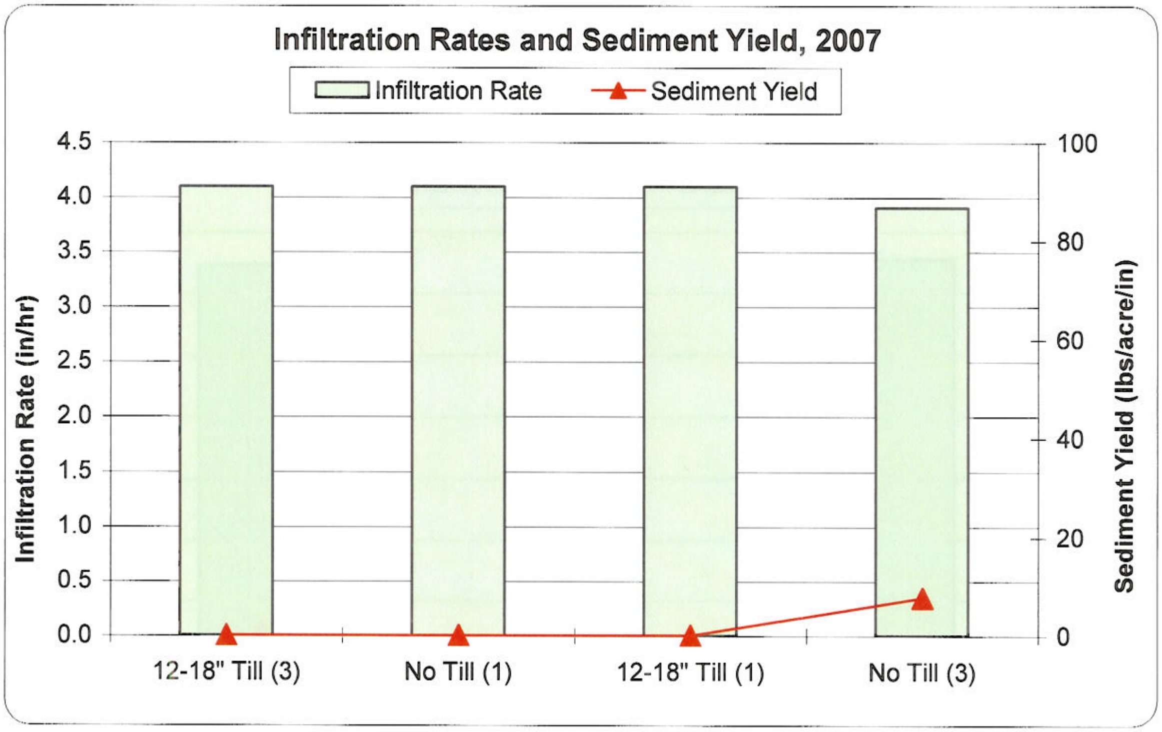

Figure 21. Infiltration Rates and Sediment Yield, 2007. All plots had similar sediment yields and infiltration rates. Sediment yield decreased from 2006 to 2007 for the 12 to 18 inch till plots at Basin #3. Graph is sorted by sediment yield.

Soil Density

The penetrometer depth to refusal (DTR) is often used as an index of soil density. A denser soil is less likely to allow infiltration. Rainfall simulations conducted on road cuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10.2 cm).[4]

Average penetrometer depths to refusal (DTR) were 1.8 times deeper (2 inches) for plots tilled 12 to 18 inches than for plots without tilling (Figure 22). The two year average for the 12 to 18 inch till plots was 6.6 inches (17 cm), while the two year average for the no till plots was 3.7 inches (9.4 cm).

The penetrometer DTR at the 12 to 18 inch till plot at Basin #3 was similar to the penetrometer DTR at the native site (Figure 22). The penetrometer DTR at the 12 to 18 inch till plot at Basin #3 was 8.2 inches (20.8 cm), while the DTR at the native site was 8.2 inches (21.3 cm). The 12 to 18 inch till plot at Basin #1 had a shallower DTR of 6 inches (15.2 cm).

[4] Grismer, M. Simulated Rainfall Evaluation at SunRiver and Mt Bachelor Highways, Oregon. Unpublished, 2006.

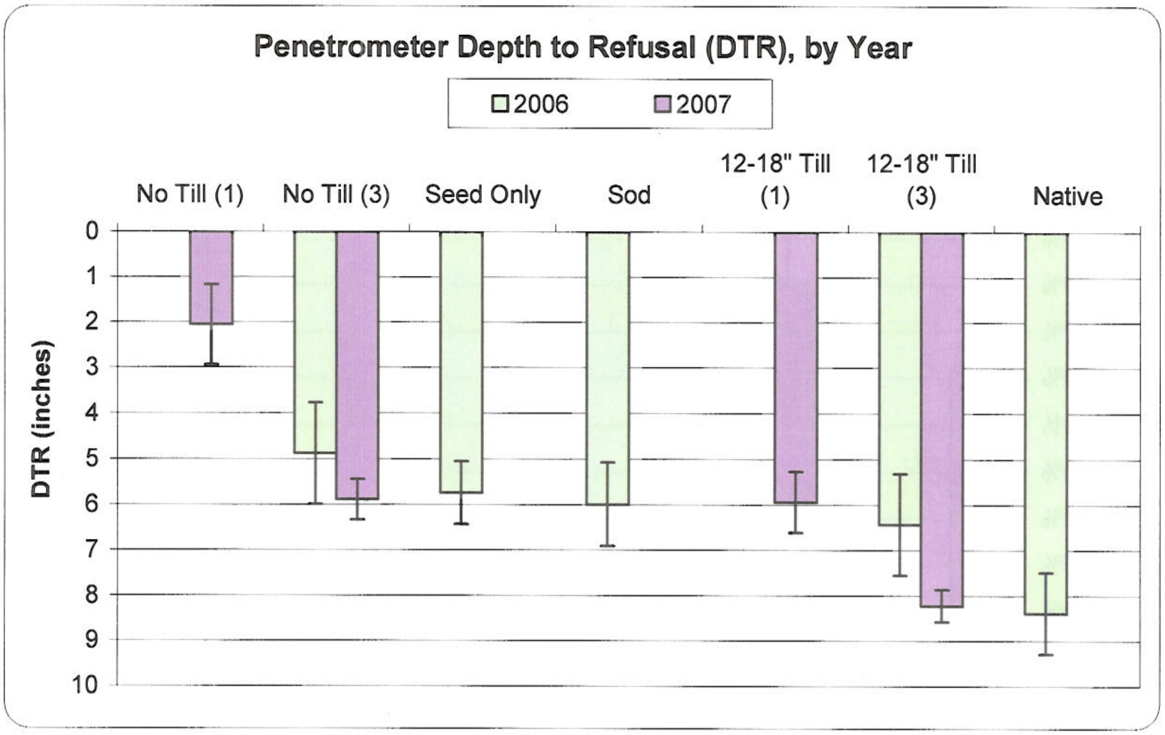

Figure 22. Penetrometer Depth to Refusal, by Year. The 12 to 18 inch tilled plots had deeper penetrometer DTRs than the DTRs at the no till plots. The DTR at 12 to 18 inch till (Basin 3) plot was similar to the native site DTR. The error bars represent one standard deviation above and below the mean.

Cover

Mulch Cover

At the 12 to 18 inch till plot at Basin #3, which did not produce sediment in 2006 or 2007, mulch cover increased from 68% to 90% (Figure 23). Overall mulch cover increased by 2% to 20% at the other treated plots from 2006 to 2007. High mulch cover is often associated with sediment reduction.[5] High ground cover by mulch (greater than 80%) at the Brockway Summit Fill Slopes most likely contributed to low sediment yields.

[5] Grismer, ME, Hogan, MP. 2004. Evaluation of revegetation/mulch erosion control using simulated rainfall in the Lake Tahoe basin: 1. Method Assessment. *Land Degrad. & Develop.* 13:573-578.

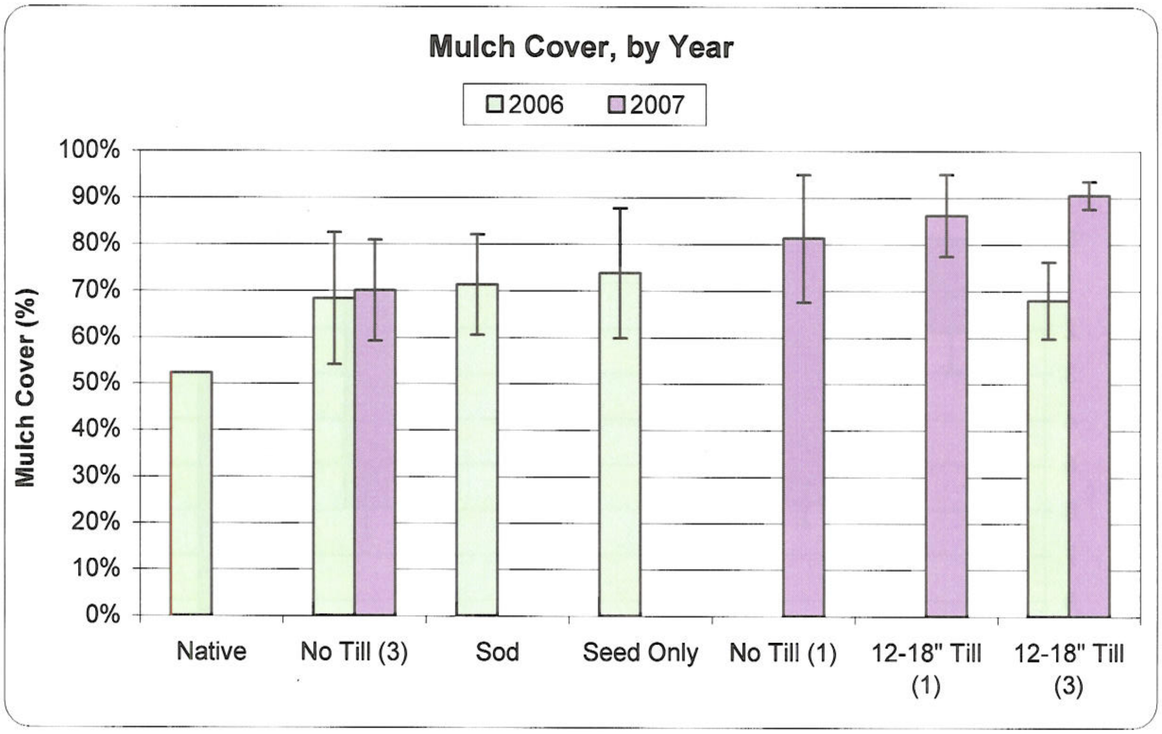

Figure 23. Mulch cover, by Year. Mulch cover increased between 2006 and 2007. The mulch cover at the native site was low because ground cover by native plants was high. The error bars represent one standard deviation above and below the mean.

Mulch Depth

There was no difference in the depth of mulch among treated sites (Figure 24). Mulch depths ranged from 0.5 to 1.45 inches (1.3 to 3.7 cm) with the lowest mulch depth at the 12 to 18 inch till plot in Basin #3 and the highest mulch cover at the no till plot in Basin #3. Mulch depth, as well as ground cover by mulch, affects erosion control. Many of the rainfall simulations that did not produce sediment were conducted on native and treated sites that had deep mulch layers (greater than 1.5 inches). The wetting depth (depth at which water infiltrated into the soil column) often did not extend past the mulch layer suggesting that, in some situations, the mulch layer is able to absorb and/or retain high rates of rainfall. Mulch depth was not related to infiltration rates or sediment yields, suggesting that other factors may have a greater influence at this site.

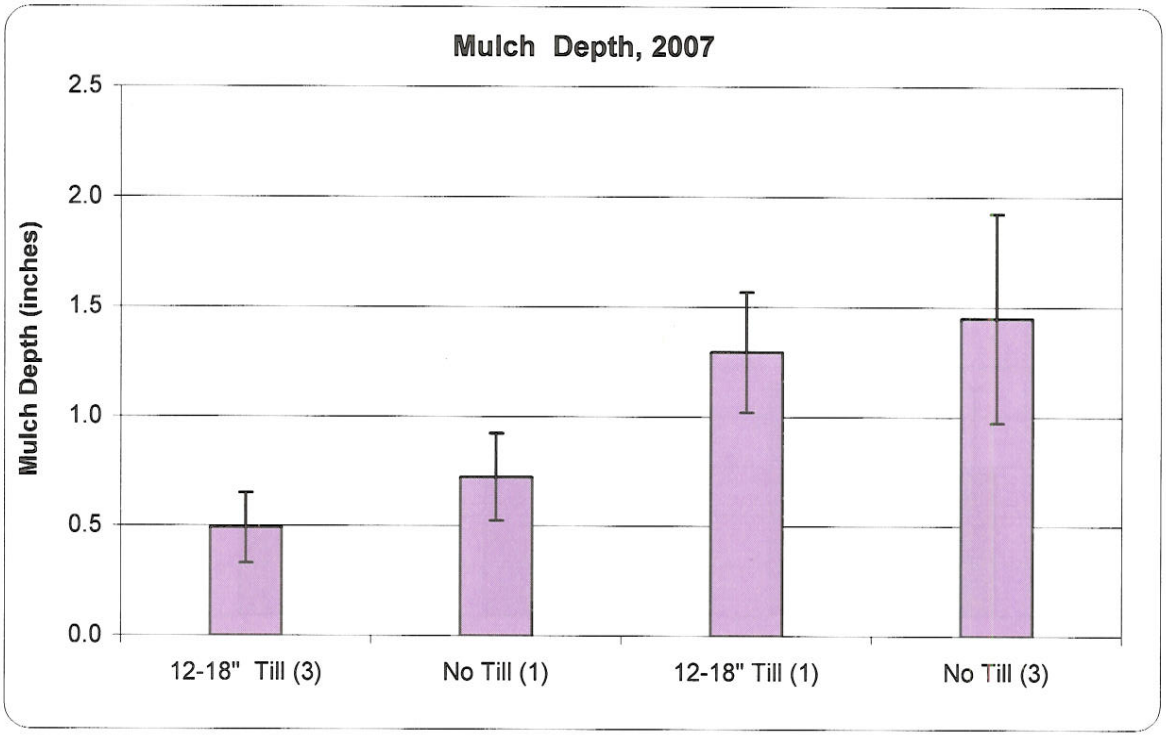

Figure 24. Mulch depth, 2007. There is no discernable difference between the mulch depths at the 12 to 18 inch till versus the no till plots. Mulch depths ranged from 0.5 to 1.45 inches. The error bars represent one standard deviation above and below the mean.

Foliar Plant Cover

The plots tilled to a depth of 12 to 18 inches showed trend towards higher foliar plant cover (67%) than the no till plots (47%), when averaged over the two sampling years (Figure 25). The highest foliar plant cover (80%) was recorded at the 12 to 18 inch till plot in Basin #1 in 2007. This cover was higher than that of the native site, 63% (Figure 25). In 2006, foliar cover at the sod plot was also higher than that at the native plot, 72%.

The difference in plant cover between plots tilled to 12 to 18 inch and no till plots did not appear to affect either the infiltration rates or the sediment yields observed during rainfall simulations (Figure 20, Figure 21, and Figure 25).

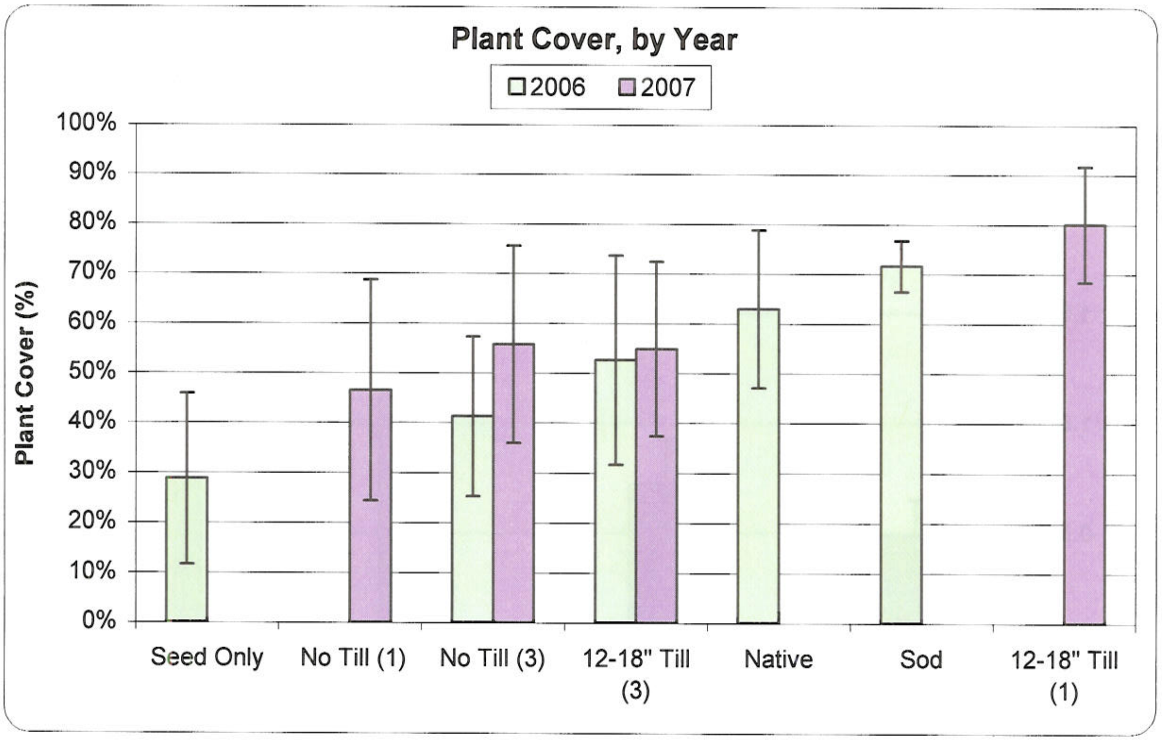

Figure 25. Plant Cover, by Year. The average plant cover was higher at the 12 to 18 inch till plots than the no till plots. Plant cover increased slightly at the no till plot (Basin 3) from 2006 to 2007. The plant cover at the 12 to 18 inch till (Basin 1) plot and the sod plot most resembled the plant cover at the native site. The error bars represent one standard deviation above and below the mean.

Plant Cover Composition

The two-year average perennial plant cover at the plots tilled to 12 to 18 inches was 21%, which was similar to the perennial plant cover at the no till plots (16%, Figure 26).

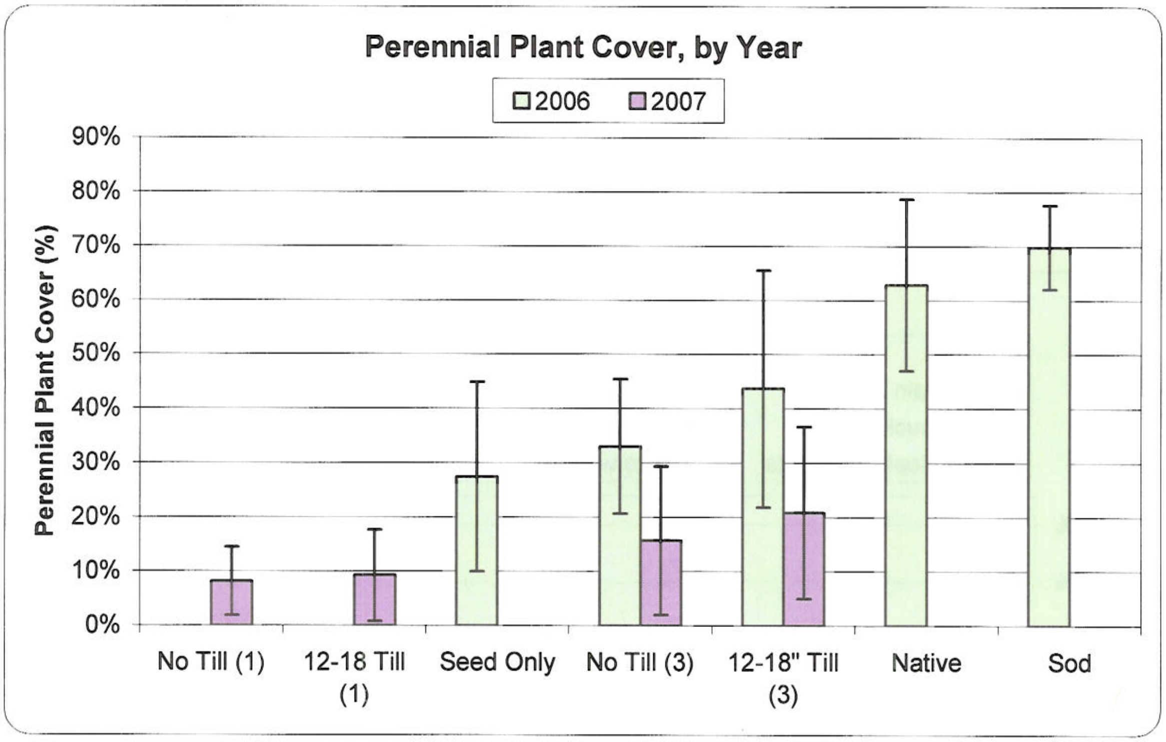

Figure 26. Foliar Perennial Plant Cover, by Year. There was a large decrease in perennial plant cover between 2006 and 2007. The decrease in perennial plant cover was not linked to an increase in sediment yield.

A decrease in perennial plant cover from 2006 to 2007 was not correlated to a decrease in infiltration rates or an increase in sediment yields (Figure 20, Figure 21, Figure 26, Figure 27, and Figure 28). In 2006, native perennial species that had been seeded composed the majority of foliar cover at treated plots. In 2007, the non-native annual species cheatgrass composed most of the foliar plant cover.

Over the two year period, buckwheat and squirreltail were the most productive seeded species (Figure 28). In the first growing season, squirreltail and mountain brome represented the majority of cover by seeded species. In the second growing season, the percentage of cover by mountain brome decreased markedly from about 16% to less than 1%, while cover by squirreltail decreased from 20% to 2% to 4%. The cover by buckwheat species increased to between 5% and 10%, making it the dominant seeded species in 2007 (Figure 28). Both squirreltail and buckwheat are more drought tolerant than mountain brome, which would explain their higher cover in 2007 when the annual precipitation was 50% of normal.

Though buckwheat provided more cover in 2007, its root systems is relatively shallow, contributing less to soil strength than the seeded, native bunchgrasses (squirreltail, mountain brome, and Western needlegrass). Native perennial plants have extensive root systems that have been shown to increase soil strength.[6] At the Northstar-at-Tahoe test plots, higher foliar cover by native perennial species was related to lower sediment yields in 2006.[7]

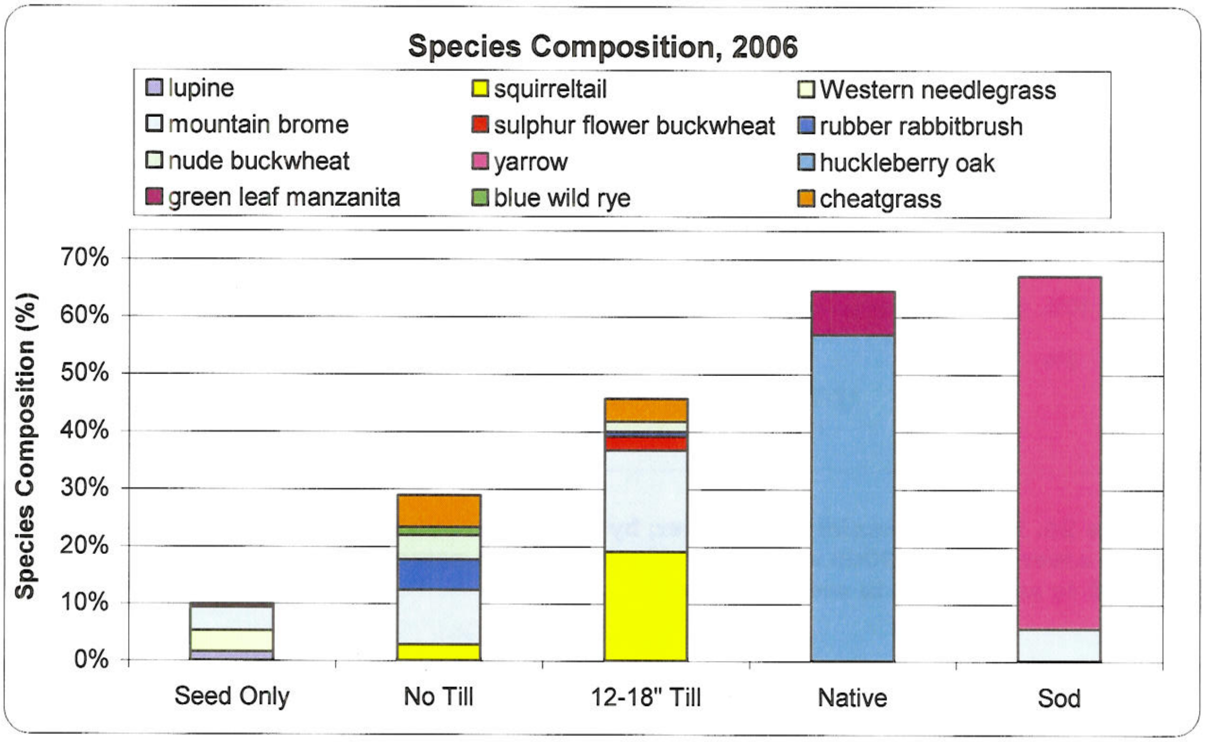

Figure 27. Species Composition, 2006. Seeded native perennials were dominant at all the treatment plots. Only dominant species are presented; therefore 100% of the foliar cover is not shown.

[6] Tengbeh, G.T. 1993. The Effect of Grass Root`s on Shear Strength Variations with Moisture Content. *Soil Technology*. Vol. 6. pp. 287-295.

[7] Monitoring and Assessment of Erosion Control Treatments in and around the Lake Tahoe Basin, Northstar-at-Tahoe Lookout Mountain Site Report, unpublished, 2006.

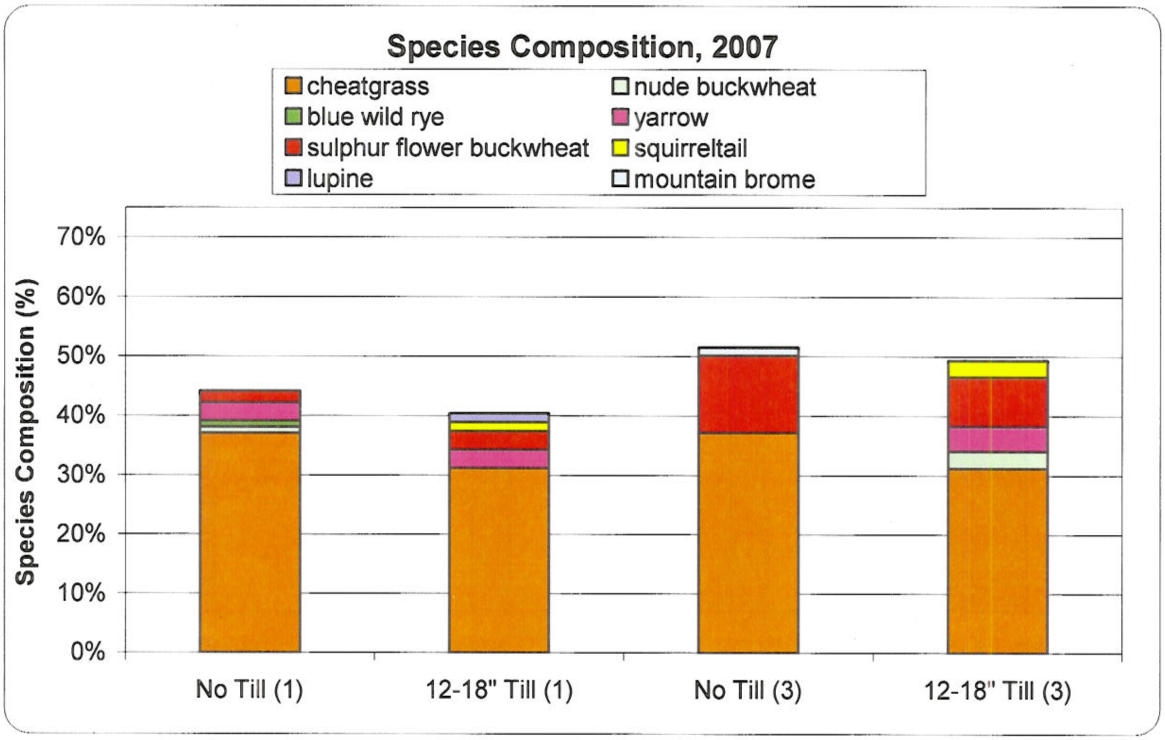

Figure 28. Species Composition, 2007. The annual species, cheatgrass, was dominant at all the plots. Only dominant species are presented; therefore 100% of the foliar cover is not shown.

Soil Nutrients

All treatments with added compost had Total Kjeldahl Nitrogen (TKN) levels above 1,500 ppm, similar to TKN at the native site (Figure 29). The organic matter content for all treatments was less than 5.3% compared to 6.6% at the native site.

The relatively high TKN level and the relatively low percentage of organic matter are a result of the high nitrogen content of screened compost that was applied at the sites (Figure 29). This higher available nitrogen increases first year plant growth, but may support establishment of fast-growing annual species over slower growing perennial species.

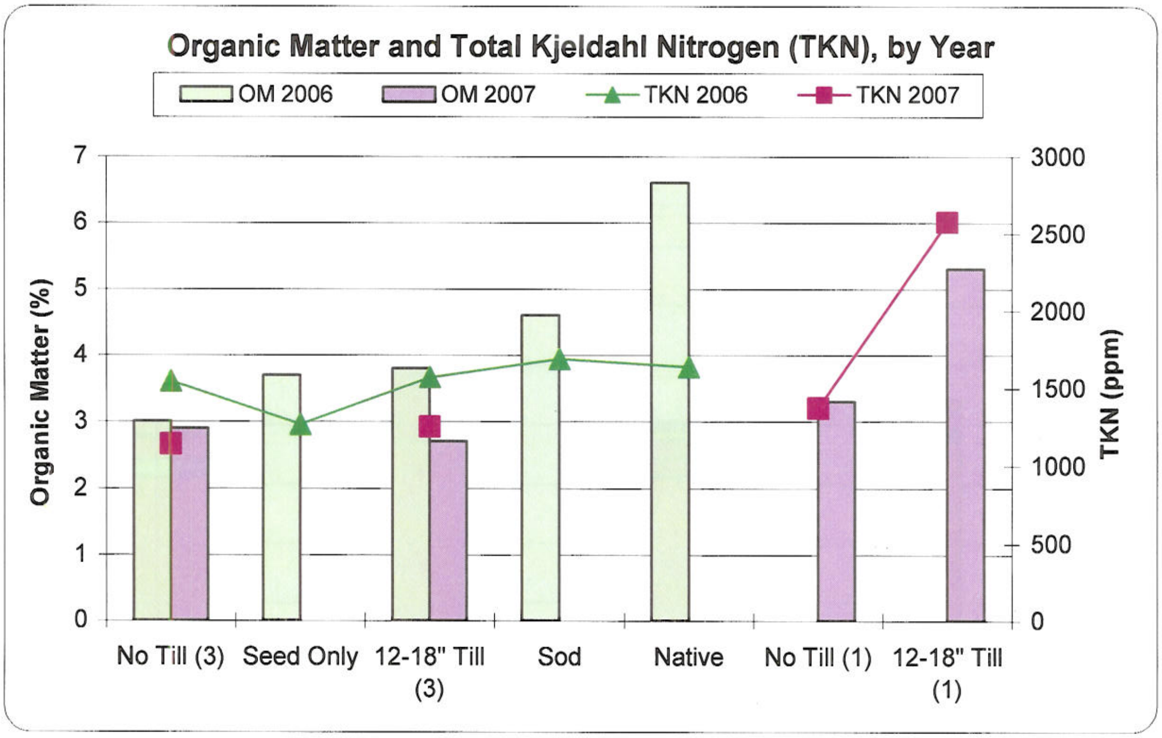

Figure 29. Organic Matter and Total Kjeldahl Nitrogen (TKN), by Year. None of the treatment plots reached the organic matter percentage of the native site. All plots amended with compost had TKN levels similar to the native TKN. Data is sorted by 2006 organic matter percentage.

Soil Shear Strength

The shear strength values for treated sites at the Brockway Fill Slopes were similar to that of a nearby native site, 31 kPa (Figure 30). Soil strength can be an important indication of a soils resistance to mass slope failure under high moisture conditions. Soil strength or a soils resistance to a shear force can be attributed to the internal structure of the soil, to woody material embedded in the soil and to the presence of plant roots. The density of plant roots has been shown to increase soil strength in laboratory tests.[8] In recently loosened soils, it is expected that soil strength would be primarily derived from woody material and plant roots because the soil has not yet developed a complex structure.

[8] Tengbeh, G.T. 1993. The Effect of Grass Roots on Shear Strength Variations with Moisture Content. *Soil Technology.* Vol. 6. pp. 287-295.

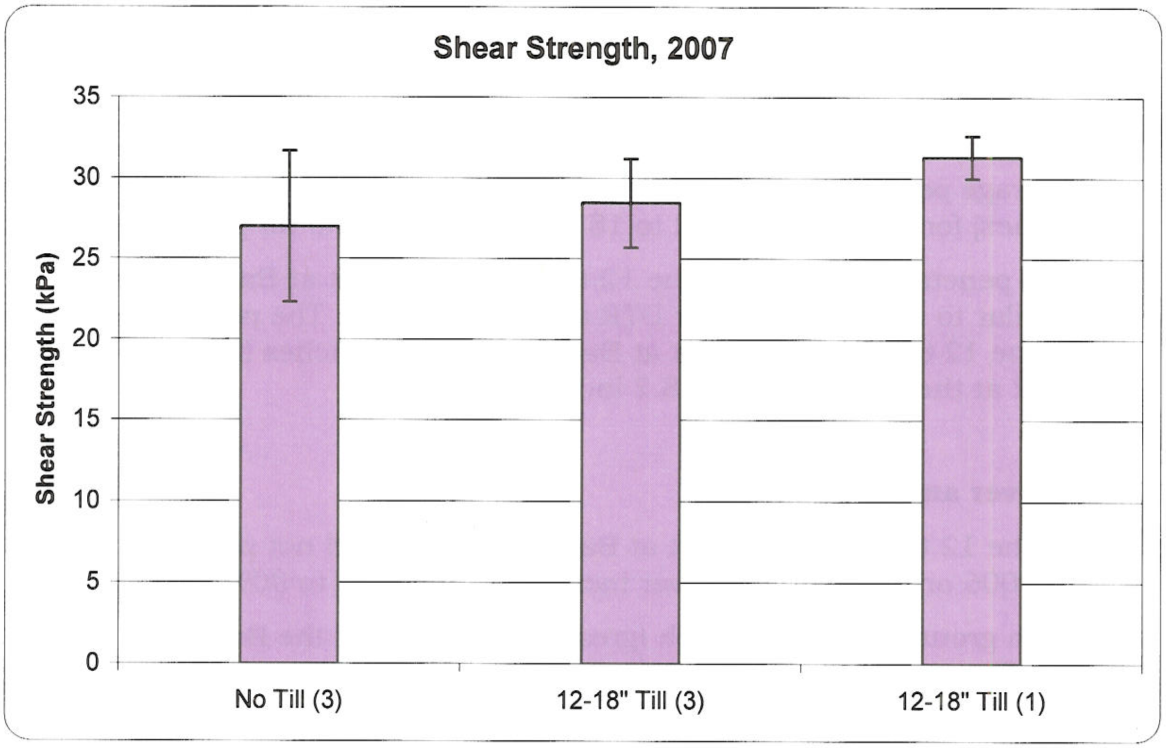

Figure 30. Shear Strength, 2007. Soil shear strength was moderate at both the 12 to 18 inch till and the no till plots. The error bars represent one standard deviation above and below the mean.

Soil Moisture

Soil moisture in August at Brockway Fill Slopes was between 3% and 6%, which has been observed as a normal soil moisture level in local volcanic soils with high solar exposure. Soil moisture affects biological activity in the soil. This activity is maximized at certain moisture levels with considerable decreases in biological activity above or below those levels.[9,10]

CONCLUSIONS

The following conclusions are grouped by soil, plant, and site characteristics that affect the erosion control capacity of a site.

Infiltration

- Little to no sediment was produced during rainfall simulation at any of the treated areas in 2006 and 2007 (Figure 20 and Figure 21).

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[9] Paul E. A. and F.E. Clark. 1989. Soil Microbiology and Biochemistry. San Diego: Academic Press

[10] Allen, M.F. 1992. Mycorrhizal Functioning. NY: Chapman and Hall.

- Greater than 90% of rainfall was infiltrated at all treated plots (Figure 20 and Figure 21).

Soil Density

- Average penetrometer depths to refusal (DTR) were 1.8 times deeper (2 inches) for plots tilled to 12 to 18 inches than for no till plots (Figure 22).
- The penetrometer DTR at the 12 to 18 inch till plot at Basin #3 was similar to the penetrometer DTR at the native site. The penetrometer DTR at the 12 to 18 inch till plot at Basin #3 was 8.2 inches (21 cm), while the DTR at the native site was 8.2 inches (21 cm).

Mulch Cover and Depth

- At the 12 to 18 inch till plot at Basin #3, which did not produce sediment in 2006 or 2007, mulch cover increased from 68% to 90%.
- High ground cover by mulch (greater than 80%) at the Brockway Summit Fill Slope most likely contributed to the low sediment yields.
- There was no difference in the depth of mulch among treated sites.
- Mulch depth was not related to infiltration rates or sediment yields, suggesting that other factors may have a greater influence at this site.

Foliar Plant Cover

- The plots tilled to a depth of 12 to 18 inches showed a trend towards higher foliar plant cover (67%) than no till plots (47%), when averaged over the two sampling years (Figure 25).
- The difference in plant cover between the 12 to 18 inch and no till plots did not affect the infiltration rate or the sediment yield during rainfall simulation (Figure 20, Figure 21, and Figure 25).

Plant Cover Composition

- The two-year average perennial plant cover at plots tilled to 12 to 18 inches (21%) was similar to the perennial plant cover at the no till plots (15%, Figure 26).
- The decrease in seeded native perennial plant cover from 2006 to 2007 did not affect measured infiltration rates or sediment yields (Figure 20, Figure 21, Figure 26, Figure 27, and Figure 28).
- The percentage of cover by mountain brome decreased markedly from about 16% to less than 1%, while cover by squirreltail decreased from about 20% to 2% to 4% (Figure 28).

- Over a two year period, buckwheat and squirreltail were the most productive seeded species.

Soil Nutrients

- All treatments with added compost had Total Kjeldahl Nitrogen (TKN) levels above 1,500 ppm, similar to TKN at the native site (Figure 29).
- The organic matter content for all treatments was less than 5.3% compared to 6.6% at the native site.
- The relatively high TKN levels and the relatively low percentage of organic matter are a result of the high nitrogen content of screened compost that was applied at the sites.

Shear Strength

- Shear strength values at the treated sites were similar to those at a nearby native site (Figure 30).

Soil Moisture

- Soil moisture in August at the Brockway Fill Slopes was between 3% and 6%, which has been observed as a normal soil moisture level in local volcanic soils with high solar exposure

RECOMMENDATIONS

These recommendations pertain to south facing, 25 degree fill slopes with high solar exposure on volcanic parent material.

<u>Tilling</u>: 12 - 18 inches (30 to 46 cm)

<u>Amendment</u>: 6 inches (10 cm) of compost composed of 25% fines and 75% coarse overs

<u>Biosol</u>: 2,000 lbs/acre (2,241 kg/ha)

<u>Seed</u>: 125 lbs/acre (140 kg/ha) seed with the following composition:

40% squirreltail
20% mountain brome
25% Western needlegrass
10% buckwheat species
5% native forbs and shrubs

<u>Mulch</u>: 2 to 3 inches (5 to 7.6 cm) of pine needle mulch to 99% cover

Tilling to 12 to 18 inches versus No Tilling

Tilling the soil to a depth of between 12 and 18 inches (30 to 46 cm) is recommended rather than no tilling for the following reasons:

- The penetrometer DTR at the 12 to 18 inch till plot at Basin #3 was similar to the penetrometer DTR at the native site.
- Average penetrometer depths to refusal (DTR) were 1.8 times deeper (2 inches) for plots tilled to 12 to 18 inches than for no till plots (Figure 22).
- Plots tilled to a depth of 12 to 18 inches showed a trend towards higher foliar plant cover (67%) than no till plots (47%), when averaged over the two sampling years (Figure 25).

Amendment

Six inches (10 cm) of compost composed of 25% fine screened material and 75% coarse overs should be incorporated instead of the tested screened compost for the following reasons:

- It is necessary to add 6 inches of the 25% fines/75% coarse overs compost versus 3 inches of screened compost to reach the same nitrogen equivalent of approximately 3,452 lbs/acre (3,869 kg/ha).
- All treatments with added compost had Total Kjeldahl Nitrogen (TKN) levels above 1,500 ppm, similar to TKN at the native site. Therefore, the nitrogen level was appropriate (approximately 3,452 lbs/acre or 3,869 kg/ha) and is recommended for further treatments (Figure 29).
- Coarse material in the recommended compost has a higher carbon to nitrogen ratio than the screened compost. Therefore, nitrogen is released more evenly over a longer period of time. This may limit growth by fast growing annual species, such as cheatgrass.

Biosol

Biosol organic fertilizer should be applied at 2,000 lbs/acre (2,241 kg/ha).

- The application is unknown for this site; however, 2,000 lbs/acre had been shown sufficient at other sites.

Seed

A seed mix composed of the following species:

40% squirreltail
20% mountain brome
25% Western needlegrass
10% buckwheat species
5% native forbs and shrubs

should be applied at a rate of 125 lbs/acre (140 kg/ha) for the following reasons:

- squirreltail and buckwheat were the most productive seeded species during a drought year
- mountain brome was the most productive species in the first growing season, a non-drought year
- some of the species seeded during treatment have shallow root systems, whereas a majority of the above recommended species have deep or strong root systems, which can contribute to higher soil strength

Mulch

Mulch should be applied to cover greater than 99% of the ground surface to a depth of 2 to 3 inches (5 to 8 cm), rather than the applied 1 inch for the following reasons:

- High ground cover by mulch (greater than 80%) at the Brockway Summit Fill Slope most likely contributed to the low sediment yields. If the initial application is too low, mulch cover may decrease below 80% over time. This could negatively affect infiltration and sediment.
- Mild disturbance at this steep site, such as infrequent foot traffic, can displace the mulch

Biosod application

Biosod is not recommended for the following reasons:

- biosod reduces species diversity, which is an essential part of healthy plant communities
- biosod is more expensive than seeding

Appendix A

Species list and ocular estimate by species at the Brockway Fill Slopes, 2006.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Phenology	In seed mix?	Seed only (%)	Compost Till (%)	Compost No Till (%)	Sod (%)	Native
Forb	Asteraceae	Achillea millefolium	yarrow	Perennial	Native		Flower	x	< 5	< 5	< 5	80	
Forb	Brassicaceae	Alyssum alyssoides	small alyssum	Annual	Alien		Seed			T			
Forb	Asteraceae	Antennaria rosea	pussy toes	Perennial	Native		Flower		< 5				
Forb	Brassicaceae	Arabis sparsiflora	elegant rockcress	Perennial	Native		Seed				T		
Forb	Chenopodiaceae	Chenopodium album	goosefoot	Annual	Alien		Seed				T		
Forb	Asteraceae	Cirsium vulgare	bull thistle	Annual	Alien	Invasive	Flower		T				
Forb	Brassicaceae	Descurainia sophia	herb Sophia	Annual	Alien	Invasive	Seed		T				
Forb	Polygonaceae	Eriogonum nudum	nude buckwheat	Perennial	Native		Flower	x	5		10 - 15		
Forb	Polygonaceae	Eriogonum umbellatum	sulfur flower	Perennial	Native		Flower		10	13	25 - 30		
Forb	Geraniaceae	Erodium cicutarium	red stem storksbill	Annual	Alien		Seed			10	< 5		
Forb	Brassicaceae	Hesperis matronalis	dame's rocket	Perennial	Alien		Flower				T		
Forb	Asteraceae	Lactuca serriola	devil's lettuce	Annual	Alien		Veg.		T	T	T		
Forb	Brassicaceae	Lepidium campestre	English pepperweed	Annual	Alien	Invasive	Seed		T	< 5	< 5	T	
Forb	Fabaceae	Lotus purshianus	Spanish lotus	Perennial	Native		Flower	x	T	< 5	T		
Forb	Fabaceae	Lupinus breweri	Brewer's lupine	Perennial	Native		Seed	x	< 5	T			
Forb	Fabaceae	Lupinus grayii	Gray's lupine, Sierra lupine	Perennial	Native		Seed	x		T			
Forb	Fabaceae	Medicago sativa	alfalfa	Perennial	Alien		Flower			< 5			
Forb	Fabaceae	Melilotus albens	white sweetclover	Annual	Alien		Flower			5	< 5		
Forb	Scrophulariaceae	Penstemon sp.	penstemon	Perennial	Native		Dead	x			T		
Forb	Hydrophyllaceae	Phacelia hastata	silverleaf phacelia	Perennial	Native		Flower			T			
Forb	Poaceae	Poa bulbosa	bulbous bluegrass	Perennial	Alien		Seed			T			
Forb	Polygonaceae	Polygonum douglasii	Douglas knotweed	Annual	Native		Flower			T	5 - 10		
Forb	Asteraceae	Sonchus asper	prickly sows ear	Annual	Alien		Flower					T	
Forb	Scrophulariaceae	Verbascum thapsus	mullen	Annual	Native	Invasive	Flower				T		
Graminoid	Poaceae	Achnatherum occidentale	Western needlegrass	Perennial	Native		Seed	x	< 5				
Graminoid	Poaceae	Agropyron dasystachium	pubescent wheatgrass	Perennial	Alien		Seed				5		
Graminoid	Poaceae	Bromus carinatus	mountain brome	Perennial	Native		Flower	x	10	30	10 - 15	5 -10	
Graminoid	Poaceae	Bromus tectorum	cheatgrass	Annual	Alien	Invasive	Seed			10	30	< 5	
Graminoid	Poaceae	Deschampsia elongata	elongated hairgrass	Perennial	Native		Seed	x	T				
Graminoid	Poaceae	Elymus elymoides	squirrel's tail grass	Perennial	Native		Flower	x	20	55		< 5	
Graminoid	Poaceae	Elymus glaucus	blue wildrye	Perennial	Native		Seed				10		

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	Phenology	In seed mix?	Seed only (%)	Compost Till (%)	Compost No Till (%)	Sod (%)	Native
Schrub	Rhamnaceae	Ceanothus prostratus	Squaw carpet	Perennial	Native								X
Shrub	Brassicaceae	Arabis holboellii	Holboel's rockcress	Perennial	Native		Seed		T				
Shrub	Ericaceae	Arctostaphylos patula	greenleaf manzanita	Perennial	Native								X
Shrub	Asteraceae	Artemisia tridentata	sagebrush	Perennial	Native			x					
Shrub	Asteraceae	Chrysothamnus nauseosus	rubber rabbitbrush	Perennial	Native		Flower	x			T		
Shrub	Asteraceae	Purshia tridentata	bitterbrush	Perennial	Native			x					
Shrub	Fagaceae	Quercus vacinifolia	huckleberry leaf oak	Perennial	Native		Veg.		T				X
Tree	Pinaceae	Abies concolor	white fir	Perennial	Native		Veg.						

T= trace amounts of cover.

Species list and ocular estimate by species at the Brockway Fill Slopes, 2007.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Noxious	In seed mix?	Compost Till (3)	Compost No Till (3)	Compost Till (1)	Compost No Till (1)
Forb	Asteraceae	Achillea millefolium	yarrow	Perennial	Native		x	<5	10	<5	<5
Forb	Asteraceae	Antennaria rosea	pussy toes	Perennial	Native			T		<5	
Forb	Brassicaceae	Descurainia sophia	herb Sophia	Annual	Alien	Invasive		T		T	
Forb	Polygonaceae	Eriogonum nudum	nude buckwheat	Perennial	Native		x		<5	5	
Forb	Polygonaceae	Eriogonum umbellatum	sulfur flower	Perennial	Native			30	15	20	15
Forb	Fabaceae	Lotus purshianus	Spanish lotus	Perennial	Native		x				
Forb	Fabaceae	Lupinus breweri	Brewer's lupine	Perennial	Native		x				
Forb	Fabaceae	Lupinus grayii	Gray's lupine, Sierra lupine	Perennial	Native		x			<5	<5
Forb	Fabaceae	Medicago sativa	alfalfa	Perennial	Alien			T			
Forb	Fabaceae	Melilotus alba	white sweetclover	Annual	Alien	Of concern		T			
Forb	Scrophulariaceae	Penstemon sp.	penstemon	Perennial	Native		x				
Forb	Brassicaceae	Sisymbrium altissimum	tumble mustard	Annual	Alien					T	T
Graminoid	Poaceae	Achnatherum occidentale	Western needlegrass	Perennial	Native		x	T		T	
Graminoid	Poaceae	Agropyron dasystachium	pubescent wheatgrass	Perennial	Alien					T	
Graminoid	Poaceae	Bromus carinatus	mountain brome	Perennial	Native		x	T	<5	T	<5
Graminoid	Poaceae	Bromus tectorum	cheatgrass	Annual	Alien	Invasive		45	40	40	55
Graminoid	Poaceae	Deschampsia elongata	elongated hairgrass	Perennial	Native		x				
Graminoid	Poaceae	Elymus elymoides	squirrel's tail grass	Perennial	Native		x	10	5	10	T
Graminoid	Poaceae	Elymus glaucus	blue wildrye	Perennial	Native					T	<5
Shrub	Brassicaceae	Arabis holboellii	Holboel's rockcress	Perennial	Native			T			
Shrub	Asteraceae	Artemisia tridentata	sagebrush	Perennial	Native		x				
Shrub	Asteraceae	Chrysothamnus nauseosus	rubber rabbitbrush	Perennial	Native		x		<5		
Shrub	Asteraceae	Purshia tridentata	bitterbrush	Perennial	Native		x				

T = trace amounts of cover, 1% or less

Of concern = not listed by the California Invasice Plant Council (CIPC), but listed for other areas with the United States Department of Agriculture (USDA)